The Effects of Management Traffic on the Local Call Processing Performance of ATM Switches Using Queue Network Models and Jackson's Theorem

Dong-Hyun Heo, Sang-Wook Chung, and Gil-Haeng Lee

This paper considers a TMN-based management system for the management of public ATM switching networks using a four-level hierarchical structure consisting of one network management system, several element management systems, and several agent-ATM switch pairs. Using Jackson's queuing model, we analyze the effects of one TMN command on the performance of the component ATM switch in processing local calls. The TMN command considered is the permanent virtual call connection. We analyze four performance measures of ATM switches—utilization, mean queue length and mean waiting time for the processor directly interfacing with the subscriber lines and trunks, and the call setup delay of the ATM switch—and compare the results with those from Jackson's queuing model.

I. INTRODUCTION

With the advent of ATM switching, there seems to be a convergence of the paradigms of the data communications and telecommunications industries; the latter have always emphasized management features. The efficient operation of ATM networks requires the management and control of ATM switches [1]-[3]; public ATM networks have additional management requirements [2], [4], [5]. The Telecommunications Management Network (TMN) is capable of managing all types of telecommunication networks and equipment as well as services [6], [7]. A TMN-based management system for management and control of ATM switch networks is composed of managers and agents that are connected to each other by the Q3 interface [8], [9]. An ATM switch control module performs functions related to call processing, charging, and maintenance. These functions are usually carried out by exchanging messages between the processors.

Hwang et al. proposed five models, each with an element management system (EMS) and subordinate agents and compared the TMN agent message processing time among them [10]. Another study analyzed the capability of an ATM switch to process local calls by examining the performance of the processors in the areas of call processing, charging, and maintenance [11]. These papers analyzed either (1) the performance of the ATM switch in processing local calls without considering the effects of the TMN-based management system that sends management and control commands to the ATM switch [12], or (2) the performance of the TMN-based management system itself [13].

Manuscript received Sept. 6, 2001; revised Oct. 24, 2002.

This study was financially supported by Chonnam National University in the program year of 2000.

Dong-Hyun Heo (phone:+82 61 464 0050,e-mail: daebulbi@empal.com) is with Jeonnam-Daebul Business Incubator Center, Jeonnam, Korea.

Sang-Wook Chung (e-mail: swchung@chonnam.ac.kr) is with the Department of Industrial Engineering, Chonnam National University, Jeonnam, Korea.

Gil-Haeng Lee (e-mail:ghlee@etri.re.kr) is with SLA Management System Team, ETRI, Daejeon, Korea.

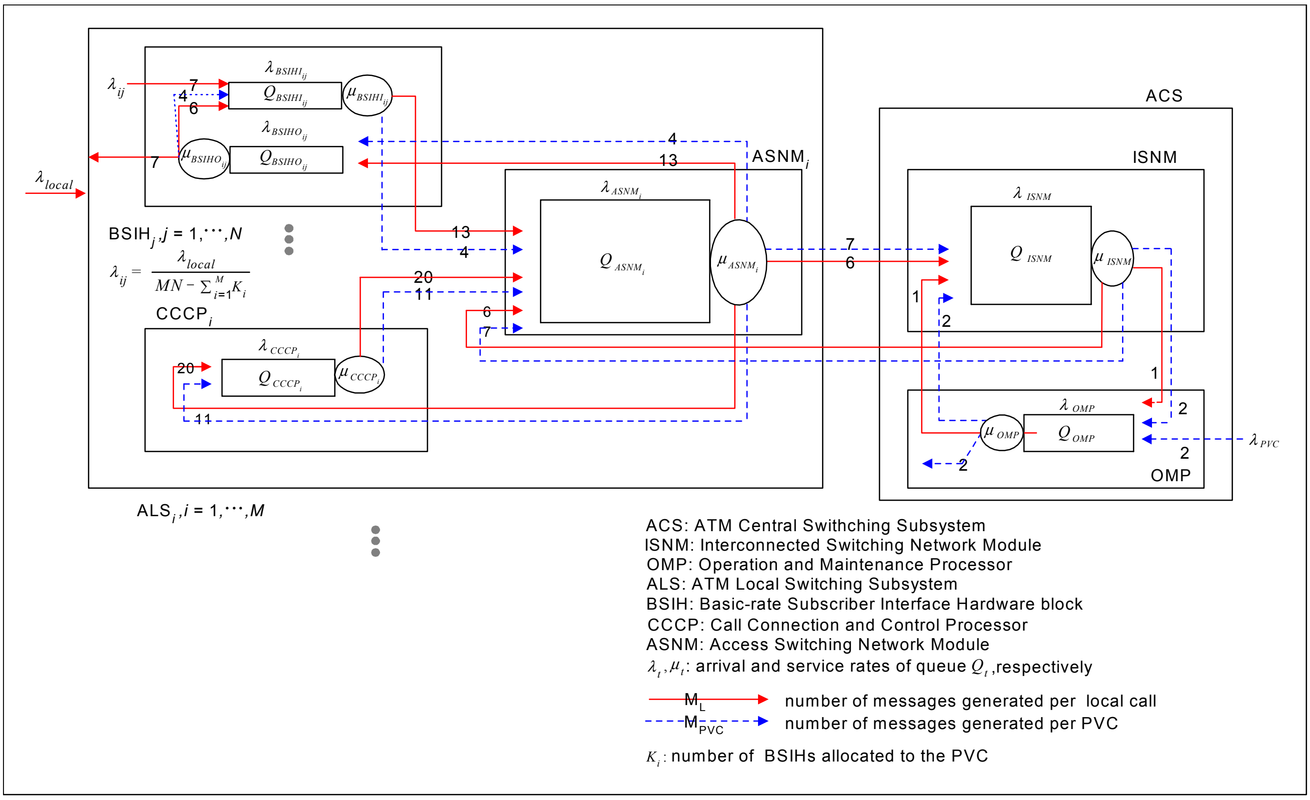

Fig. 1. Queuing network model.

In this paper, using Jackson's network model, we analyze the effects of TMN-based management functions on the local call processing performance of ATM switch. The TMN-based management system and the ATM switches considered in this paper were developed by the Electronics and Telecommunications Research Institute (ETRI) [3], [10], [11], [14]. The TMN-based management system of ETRI uses the Q3 interface between the TMN manager and agent and has implemented Q.811 and Q.812 Recommendations [10], [13]. The agent, connected to the ATM switch via a local interface and acting as a q adaptor function (QAF), parses common management information protocol (CMIP) messages, translates them into the human-machine interface (HMI) and sends them to the ATM switch. The information models for components of the ATM switch are based on the I.751, M.3100, and X.72x series [3], [9], [15]. The TMN-based management command that we consider governs the processing-intensive tasks of the permanent virtual connection (PVC). We analyze four ATM switch performance measures: utilization, mean queue length and mean waiting time for the processor to directly interface with the subscriber lines, and the call setup delay of the ATM switch. We compare our simulation results with the results from Jackson's queuing model.

II. THE QUEUING NETWORK MODEL

Jackson's theorem is widely used for analyzing open networks. It shows that even large networks of M/M/m queues can be solved relatively simply by multiplying the results for each queue [16]-[19].

Figure 1 shows a queuing network of the ATM switches managed by the TMN-based management system. The dotted lines represent the flow of messages generated by a PVC command from the TMN-based management system, and the solid lines represent the flow of messages by a local call from a subscriber line. The figures on the lines are the number of messages generated per PVC command or local call. The call connection control processors (CCCPs) perform the call connection and control functions by exchanging messages from and to N basic-rate subscriber interface hardware blocks (BSIHs). Messages are exchanged among M CCCPs and an operation and maintenance processor (OMP) via the interconnected switching network module (ISNM). We consider the PVC command as representative because it requires more capacity of the CCCP than other traffic commands affecting the local call capability of CCCPs.

Table 1. Arrival rates of queues.

	Local call processing only	Both local and PVC call processing
$\lambda_{BSIHI_{ij}}$	$7\lambda_{ij}+\frac{6}{13}\lambda_{BSIHO_{ij}}=\frac{13}{MN}\lambda_{local}$	$\frac{13}{MN-\sum_{i=1}^{M}K_i}\lambda_{local}+\frac{4}{\sum_{i=1}^{M}K_i}\lambda_{PVC}$
$\lambda_{BSIHO_{ij}}$	$\frac{1}{3N}\lambda_{ASNM_i}=\frac{13}{MN}\lambda_{local}$	$\frac{13}{MN-\sum_{i=1}^{M}K_i}\lambda_{local}+\frac{4}{\sum_{i=1}^{M}K_i}\lambda_{PVC}$
λ_{ASNM_i}	$\sum_{j=1}^{N}\lambda_{BSIHI_{ij}}+\lambda_{CCCP_i}+\frac{6}{7M}\lambda_{ISNM}=\frac{39}{M}\lambda_{local}$	$\frac{39}{M}\lambda_{local}+\frac{176}{8M}\lambda_{PVC}$
λ_{CCCP_i}	$\frac{20}{39}\lambda_{ASNM_i}=\frac{20}{M}\lambda_{local}$	$\frac{20}{M}\lambda_{local}+\frac{11}{M}\lambda_{PVC}$
λ_{ISNM}	$\frac{6}{39}\sum_{i=1}^{M}\lambda_{ASNM_i}+\lambda_{OMP}=7\lambda_{local}$	$7\lambda_{local}+9\lambda_{PVC}$
λ_{OMP}	$\frac{1}{7}\lambda_{ISNM}=\lambda_{local}$	$\lambda_{local}+4\lambda_{PVC}$

III. A NUMERICAL ANALYSIS

Here we make a numerical analysis of the effects of λ_{PVC} on the CCCP$_i$s utilization, mean queue length and mean waiting time, and call setup delay. We assume that (1) K_i BSIHs for each ATM local switching subsystem (ALS$_i$) are allocated to processing the PVC calls, (2) the local calls from the basic-rate subscribers are distributed uniformly among the remaining BSIHs, and (3) local calls and PVC commands are generated in a Poisson distribution [10], [13], [20]. The first column of Table 1 shows the arrival rates of queues when an ATM switch is used for processing local calls only. For an ATM switch processing both local calls and PVC commands, the arrival rates of queues are listed in the last column of Table 1. Following Jackson's theorem on queuing networks, $\lambda_j=a_j+\sum_{i=1,i\neq j}^{l}r_{ij}\lambda_i$, where $i=1,\cdots,L$, the arrival rate of queue j is equal to the sum of the arrivals a_j, and from outside the system the arrivals $r_{ij}\lambda_i$ from queue i to queue j and r_{ij} is the routing probability from queue i to queue j.

Take Q_{CCCP_i} as an example of a local call only. The arrival rate from outside the system to Q_{CCCP_i} is none, $a_j=0$, and the arrivals from queue Q_{ASNM_i} to Q_{CCCP_i} are $\frac{20}{39}\lambda_{ASNM_i}$ ($\sum_{i=1,i\neq j}^{l}r_{ij}\lambda_i=\frac{20}{39}\lambda_{ASNM_i}$).

Based on a message processing analysis of the queues [20]-[22], we further assume that (4) the mean processing time of each of the queues of BSIHI$_{ij}$, BSIHO$_{ij}$, ASNM$_i$, and ISNM is linearly proportional to the length of the message to be processed and (5) their processing times follow an independent exponential behavior with their mean processing time [11]. The p_n is the probability that a message is composed of n cells, and d represents the processing time per cell. The last two columns of Table 1 show the service rates calculated under the assumed distributions of p_n and the values of d [21]. Thus, the mean time required to process a message with a length of n cells may increase linearly as n does, that is, $\sum_n p_n nd$ [21]. We assume the service rates of queues CCCP$_i$ and OMP are 1000 messages per second [11], the messages queued are processed according to the FIFO rule, and their processing times follow an independent exponential behavior [20], [21].

Under the above assumptions, formulas for the utilization of CCCP$_i$, mean queue length and mean waiting time of CCCP$_i$, and call setup delay can be easily calculated using Jackson's theorem [16], [17] as follows:

- The utilization of CCCP$_i$

$$\rho_{CCCP_i}=\frac{\lambda_{CCCP_i}}{\mu_{CCCP_i}}$$

- The mean queue length of CCCP$_i$

Table 2. Service rates of $Q_{BSIHI_{ij}}$, $Q_{BSIHO_{ij}}$, Q_{ASNM_i}, and Q_{ISNM}.

	p_n		d (sec)	Service rates	
	local calls only	both local and PVC calls		local calls only	both local and PVC calls
$\mu_{BSIHI_{ij}}$ or $\mu_{BSIHO_{ij}}$	$11/13 \quad n=1$ $1/13 \quad n=2$ $1/13 \quad n=6$ $0 \quad \text{otherwise}$	$15/17 \quad n=1$ $1/17 \quad n=2$ $1/17 \quad n=6$ $0 \quad \text{otherwise}$	$2.12\text{E}-6$	$\frac{13\text{E}6}{19\times 2.12}$	$\frac{17\text{E}6}{23\times 2.12}$
μ_{ASNM_i}	$26/39 \quad n=1$ $7/39 \quad n=2$ $2/39 \quad n=4$ $2/39 \quad n=6$ $2/39 \quad n=9$ $0 \quad \text{otherwise}$	$42/61 \quad n=1$ $9/61 \quad n=2$ $4/61 \quad n=4$ $2/61 \quad n=6$ $4/61 \quad n=9$ $0 \quad \text{otherwise}$	$1\text{E}-6$	$\frac{1\text{E}6}{2}$	$\frac{61\text{E}6}{124}$
μ_{ISNM}	$2/7 \quad n=1$ $2/7 \quad n=2$ $2/7 \quad n=4$ $1/7 \quad n=9$ $0 \quad \text{otherwise}$	$6/15 \quad n=1$ $4/15 \quad n=2$ $3/15 \quad n=4$ $2/15 \quad n=9$ $0 \quad \text{otherwise}$	$1\text{E}-6$	$\frac{7\text{E}6}{23}$	$\frac{15\text{E}6}{44}$

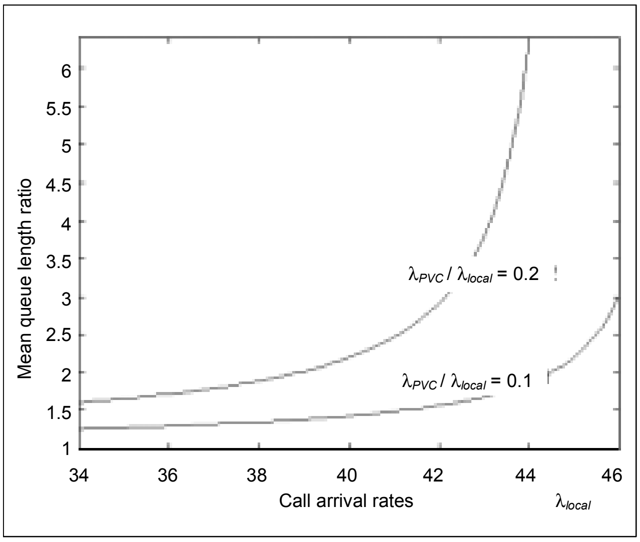

Fig. 2. Effect on CCCP utilization (ρ_{CCCP_i}).

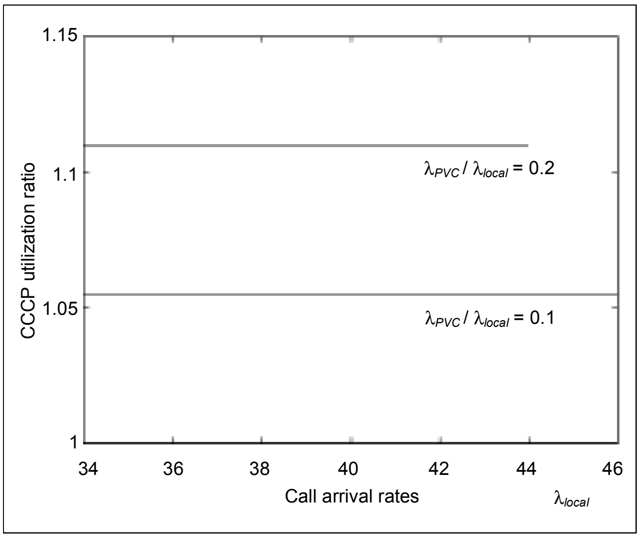

Fig. 3. Effect on mean queue length (L_{CCCP_i}).

$$L_{CCCP_i} = \frac{\rho_{CCCP_i}}{1-\rho_{CCCP_i}}$$

- The mean waiting time of CCCP$_i$

$$W_{CCCP_i} = \frac{1}{\mu_{CCCP_i} - \lambda_{CCCP_i}}$$

- The call setup delay

$$D = 11 \cdot W_{CCCP_i} + W_{OMP},$$

where W_k is the mean waiting time of queue *k*.

Eleven messages are processed at the CCCP$_i$ and one at the OMP during the call setup [11], [22]. For Figs. 2 to 5, we assume that an ATM switch processes both local and PVC calls

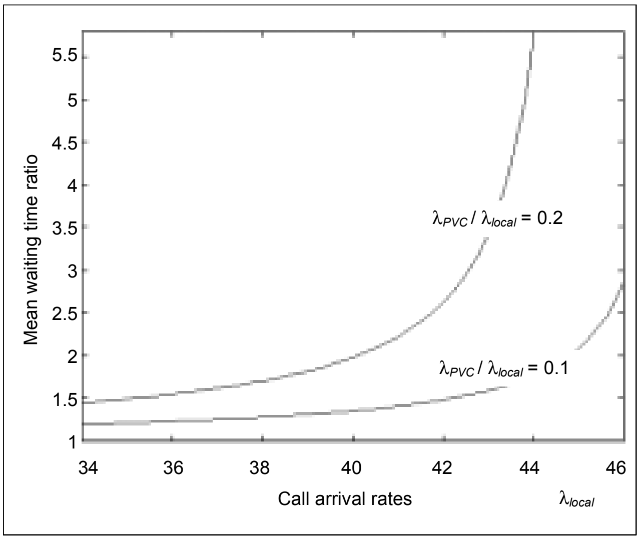

Fig. 4. Effect on mean waiting time (W_{CCCP_i}).

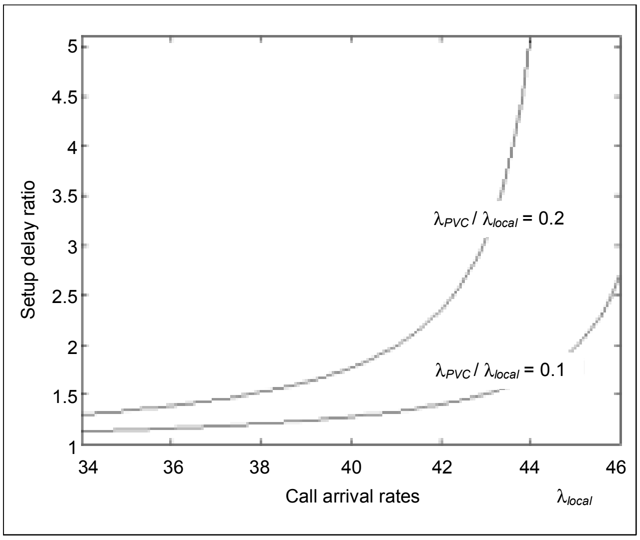

Fig. 5. Effect on call setup delay (D).

and one ALS has 15 BSIHs, among which 14 BSIHs are allocated to local calls and one to both local and PVC calls; these figures show the ratios of ρ_{CCCP_i}, L_{CCCP_i}, W_{CCCP_i}, or D when processing both local and PVC calls to $\rho_{CCCP_i}, L_{CCCP_i}, W_{CCCP_i}$, or D when processing local calls only. We chose the values of 0.2 and 0.1 for $\lambda_{PVC}/\lambda_{local}$ on the basis of the performance of the TMN agent processor [10], [13].

From these figures we can see that (1) the effect of λ_{PVC} on the four measures is considerable, (2) the effect of λ_{local} on ρ_{CCCP_i} is negligible, and (3) the effect of λ_{local} on other measures is substantial. As these figures showing the effect of PVC traffic reveal, carefully considering such effects is useful in designing the TMN-based management system for ATM switches.

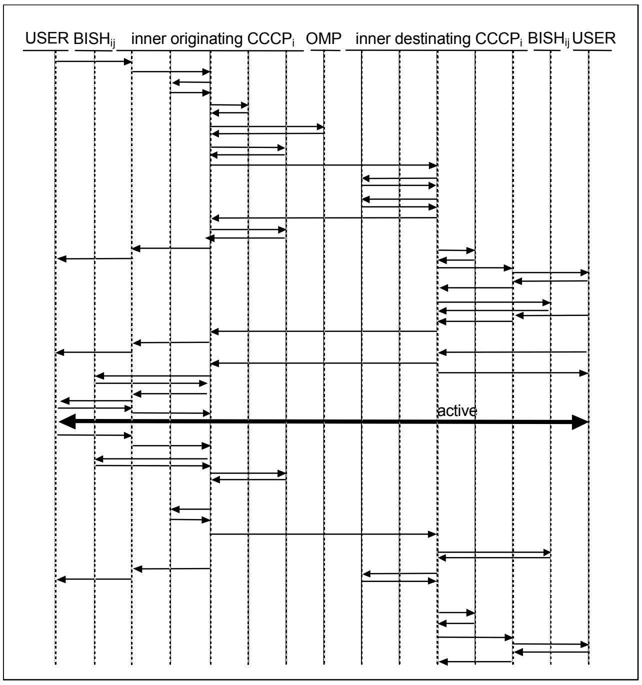

Fig. 6. Local call connection procedure.

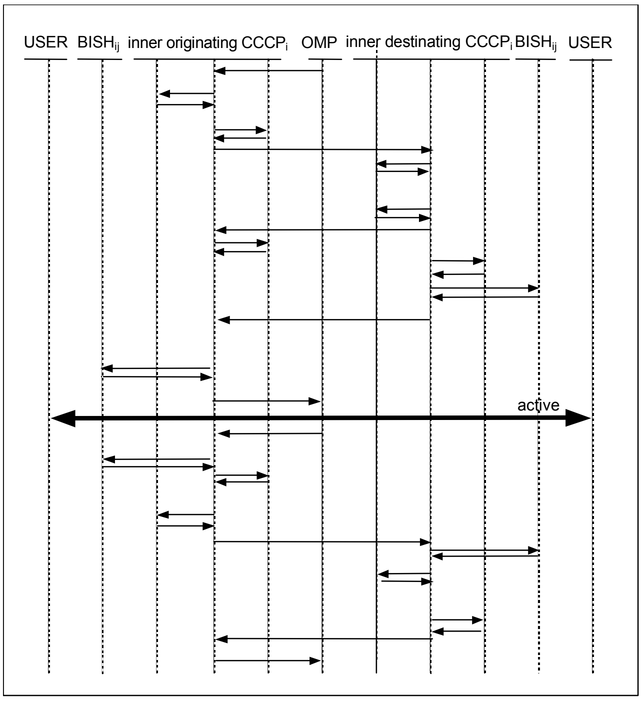

Fig. 7. Point-to-point PVC procedure.

For a comparison of $\rho_{CCCP_i}, L_{CCCP_i}, W_{CCCP_i}$, and D from Jackson's queuing model, we performed a Monte Carlo simulation using the AweSim tool, which is basically the

Table 3. Comparison of Jackson's Theorem and Simulation Results.

	call arrivals (λ_{local})	local calls only		both local and PVC calls ($\lambda_{PVC}/\lambda_{local}=0.1$)		both local and PVC calls ($\lambda_{PVC}/\lambda_{local}=0.2$)	
		numerical result	simulation result	numerical result	simulation result	numerical result	simulation result
Utilization (ρ_{CCCP_i})	34	0.68	0.67	0.717	0.713	0.755	0.756
	36	0.72	0.72	0.759	0.752	0.799	0.804
	38	0.76	0.76	0.802	0.792	0.844	0.847
	40	0.80	0.80	0.844	0.834	0.888	0.900
	42	0.84	0.83	0.886	0.881	0.9324	0.935
	44	0.88	0.88	0.928	0.928	0.9768	0.974
	46	0.92	0.92	0.9706	0.964	Case for which $\rho_{CCCP_i} \geq 1$	
Queue Length (L_{CCCP_i})	34	1.445	1.387	1.821	1.650	2.324	2.399
	36	1.851	1.850	2.400	2.284	3.181	3.254
	38	2.407	2.309	3.244	2.951	4.550	4.408
	40	3.200	3.260	4.566	4.231	7.041	7.670
	42	4.410	4.316	6.901	6.424	12.861	15.051
	44	6.453	6.727	12.038	13.201	41.126	38.336
	46	10.580	9.849	32.043	28.979	Case for which $\rho_{CCCP_i} \geq 1$	
Waiting time (W_{CCCP_i})	34	0.002	0.002	0.003	0.002	0.003	0.003
	36	0.003	0.003	0.003	0.003	0.004	0.004
	38	0.003	0.003	0.004	0.004	0.005	0.005
	40	0.004	0.004	0.006	0.005	0.008	0.009
	42	0.005	0.005	0.008	0.007	0.014	0.016
	44	0.007	0.008	0.013	0.013	0.0421	0.039
	46	0.012	0.011	0.033	0.030	Case for which $\rho_{CCCP_i} \geq 1$	
Delay (D)	34	0.034	0.034	0.035	0.034	0.041	0.045
	36	0.045	0.045	0.042	0.045	0.050	0.056
	38	0.045	0.045	0.050	0.056	0.064	0.067
	40	0.056	0.056	0.064	0.067	0.089	0.111
	42	0.067	0.067	0.088	0.089	0.148	0.189
	44	0.089	0.100	0.140	0.143	0.431	0.451
	46	0.144	0.133	0.340	0.342	Case for which $\rho_{CCCP_i} \geq 1$	

SLAM II simulation package incorporating the visualization-modeling interface [23], [24]. Figures 6 and 7 depict the simulated sequences of messages for local calls [11], [14] and PVC commands, respectively, generated on the basis of Q.2931 Recommendation [25] and ETRI implementations.

Table 3 reveals that for local calls only and both local and PVC calls, Jackson's network and our simulation have comparable results.

IV. CONCLUSION

This paper has analyzed the effects of TMN-based management traffic on the performance of local call processing by ATM switches using Jackson's theorem. The analysis of the effects of λ_{PVC} on CCCP utilization, mean queue length and mean waiting time, and call setup delay demonstrates that the effects of PVC commands on the performance of local call processing by ATM switches are significant and deserve to be taken into consideration. Our small-scale simulation shows that the results of Jackson's queuing model are useful for network design and analysis.

The number of ATM switches to be managed by TMN-based management systems should be determined by considering both the assumed local call and PVC command traffic. Non-Poisson PVC traffic and the pattern of the various incoming data rates will be simulated in a future research project.

REFERENCES

[1] J. Fowler, "TMN-Based Broadband ATM Network Management," *IEEE Communications Magazine*, Mar. 1995, pp. 74-85.

[2] Daniel W.K. Hong, C.S. Hong, D.S. Yun, J.H. Yoo, and W.-S. Kim, "An ATM Network Management System for Point-to-Multipoint Reservation Service," *ETRI J.*, vol. 24, no. 4, Aug. 2002, pp. 299-310.

[3] Y.H. Hwang, S.W. Chung, G.-H. Lee, and Y.I. Kim, "A Performance Analysis of TMN Systems Using Models of Networks of Queues, Jackson's Theorem, and Simulation," *ETRI J.*, vol. 24, no. 5, Oct. 2002, pp. 381-390.

[4] G.M. Lee, J.K. Choi, M.K. Choi, M.S. Lee and S.-G. Jong "Flow-Based Admission Control Algorithm in the DiffServ-Aware ATM-Based MPLS Network," *ETRI J.*, vol. 24, no. 1, Feb. 2002, pp. 43-55.

[5] Y.M. Jang, "Estimation and Prediction-Based Connection Admission Control in Broadband Satellite Systems," *ETRI J.*, vol. 22, no. 4, Dec. 2000, pp. 40-50.

[6] J.-Y. Kwak, J.-S. Nam, and D.-H. Kim, "A Modified Dynamic Weighted Round Robin Cell Scheduling Algrithm," *ETRI J.*, vol. 24, no. 5, Oct. 2002, pp. 360-372.

[7] K. Udupa, *TMN Essentials*, McGraw-Hill, New York, 1998.

[8] ITU-T M.3010, *TMN Management Overview*, 1996.

[9] ITU-T I.751, *Asynchronous Transfer Mode Management of the Network Element View*, 1996.

[10] H.S. Hwang, B.Y. Lee, G.H. Lee, and W.D. Woo, "Implementation of TMN Agent for ATM switch: Considering Integration of Agent into ATM Switch," *KISC Journal*, vol. 23, no. 5, May 1998, pp. 1360-1371.

[11] H.G. Yeo, K.S. Song, and S.H. Ro, "Local Call Processing Delay of the Control Network in ATM Switching System," *KISC Journal*, vol. 21, no. 12, Dec. 1996, pp.3144-3153. [in Korean]

[12] K.M Lye and K.G. Seah, "Performance of a Delta ATM Switch," *Computer Communications*, vol. 20, 1997, pp. 1203-1215.

[13] W.D. Woo, H.S. Hwang, and B.N. Yoon, "Throughput Evaluation of TMN EMS for ATM Switch," *Proc. of ITS*, vol. 2, Aug.1998, pp. 566-570.

[14] Y.B. Kim, S.S. Lee, C.H. Oh, Y.S. Kim, C.H. Han, and C.H. Yim, "An Architecture of Scalable ATM Switching System and Its Call Processing Capacity Estimation," *ETRI J.*, vol. 18, no. 3, Oct. 1996, pp. 107-125.

[15] H.S. Hwang, Y.W. Nam, S.J. Kim, B.Y. Lee, and G.H. Lee, "The Design of TMN-based Fault Management Function for ATM Switching System in Korea," *Proc. of IEEE ICCS/ISPACS'96*, vol. 2 of 3, Nov. 1996, pp. 860-863.

[16] G. Harrison and M. Patel, *Performance Modeling of Communication Networks and Computer Architectures*, Addison-Wesley, 1992

[17] K. Molloy, *Fundamentals of Performance Modeling*, Macmillan, New York, 1989.

[18] R. Jackson, "Network of Waiting Lines," *Operation Research*, vol. 5, no. 4, 1957, pp. 518-521.

[19] R. Jackson, "Jobshop-like Queuing Systems," *Management Science*, vol. 10, no. 1, 1963, pp.131-142.

[20] B.H. Choi, "Rate Proportional SCFQ (RP-SCFQ) Algorithm for High-Speed Packet-Switched Networks," *ETRI J.*, vol. 22, no. 3, Sept. 2000, pp. 1-9.

[21] G.M. Park, S.Y. Kang, and C.M. Han, "Performance Evaluation of a Cell Reassembly Mechanism with Individual Buffering in an ATM Switching System," *ETRI J.*, vol. 17, no. 1, Apr. 1995, pp. 23-36.

[22] S.J. Kim, "Estimation of Minimum Bandwidth of IPC Link," *Technical Memo*, ETRI, 1996. [in Korean]

[23] A. Alan and B. Pritsker, *Introduction to Simulation and SLAM II*, 4th ed., John Wiley & Sons, New York, 1995.

[24] Pritsker, A.A.B and O'Reilly Jean, "AweSim: The Integrated Simulation," *Proc. of Winter Simulation Conf.*, 1998, pp. 249-255.

[25] ITU-T Q.2931, *B-ISDN Application Protocols for Access Signaling*, 1995.

Dong-Hyun Heo received MS degree in industrial engineering from Chonnam National University, Korea, in 2001. He is a Co-researcher at Chonnam National University and a Manager at Chonnam-Daebul Business Incubator Center, Korea. His research areas are system performance analysis and network security.

Sang-Wook Chung received his PhD in industrial engineering from KAIST (Korea Advanced Institute of Science and Technology) in 1992. He has been an Associate Professor of Industrial Engineering at Chonnam National University since 1999. His research areas are system performance analysis, reliability analysis, product quality assurance, and optimal design of accelerated life tests.

Gil-Haeng Lee is a Principal Member of Engineering Staff and Team Leader at ETRI, Korea. He received MS and PhD degrees in computer science from KAIST in 1986 and 1996. His research interests are load balancing and distributed processing, network management, speech recognition, and real time DBMS.